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CURRENT COLLECTOR FOR HIGH-TEMPERATURE FUEL CELL
[Stromkollektor für Hochtemperatur-Brennstoffzelle]

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TECHNICAL FIELD

/2*

High-temperature fuel cells for converting chemical energy into electrical energy. Due to their high efficiency compared to other conversion methods, electrochemical-energy conversion and the devices required for it are gaining in importance.

This invention relates to the further development of electrochemical high-temperature cells using ceramic solid electrolytes as ionic conductors, whereby the cells should be largely independent of the fuel used and allow a space-saving arrangement.

In a narrower sense, invention relates to a current collector for carrying current between adjacent flat, planar, stacked high-temperature fuel cells with solid electrolyte based on doped, stabilized zirconium oxide, whereby in each case the oxygen electrode of one fuel cell is electrically connected to the fuel electrode of the subsequent fuel cell and the intermediate space between the electrodes is divided by a gas-tight, electrically conductive separating plate into two spaces, which carry the different gaseous media, fuel and oxygen carrier.

PRIOR ART

High-temperature fuel cells with ceramic solid electrolyte are known from numerous publications. The actual elements for such cells may have the most varied shapes and dimensions. In order to keep ohmic

* Numbers in the margin indicate pagination in the foreign text.

voltage losses low, every effort is made to keep the thickness of the electrolyte layer as low as possible. The shape and dimensions of the elements also depends on the need for electrically connecting in series a plurality of cells, in order to achieve the required voltage between terminals and to keep the currents relatively low. Elements exist in the form of:

Cylindrical tubes (Westinghouse),

Conical tubes, similar to "horsetail" (Dornier)

Trapezoidal shafts (Argonne)

Circular plates (ZTEK).

In the past, the development of fuel cells with a ceramic solid electrolyte has limited itself almost exclusively to improving and reducing the cost of the ceramic component, in the form of tubular fuel cell element. There is practically no reference to suitable arrangements for the optimum utilization of space or for achieving high voltages by using advantageous configurations for the series-arrangement of individual cells.

In the case of a stacked arrangement, a plurality of plate-like planar fuel cells, similar to the filter-press principle, must conduct the current perpendicular to the plane of the plates from the oxygen electrode of one cell to the fuel electrode of the next cell. Essential components for this function are separating plates (bipolar plates) and electrical connecting elements to the electrodes (current collector). In many respects, the materials used in previously known

components are insufficient with regard to modern requirements on design and construction and on long-term behavior.

The known basic elements used in fuel cells are mainly characterized by a comparatively complex geometry, making the construction of compact, space-saving devices difficult. Moreover, it is hardly possible to produce the proposed forms rationally and in large numbers. In particular, there is no configuration for an optimum series connection of individual cells that can be implemented by simple manufacturing means.

Thus, there is a great need for additional development, simplification, and rationalization of the design and construction of the basic components and for their optimal mutual arrangement, based on ceramic high-temperature fuel cells.

The following publications may be mentioned as prior art:

- O. Antonsen, W. Baukal, and W. Fischer, "Hochtemperatur-Brennstoffbatterie mit keramischem Elektrolyten" [High-Temperature Fuel Battery with Ceramic Electrolytes", Brown Boveri Mitteilungen January/February 1966, pp. 21-30,
- US-A- 4,692,274 /3
- US-A-4,395,468
- W. J. Dollard and W. G. Parker "An Overview of the Westinghouse Electric Corporation Solid Oxide Fuel Cell Program", Extended Abstracts, Fuel Cell Technology and Applications, International Seminar, The Hague , Netherlands, 26 to 29 October, 1987.

- W. J. Rohr, High-Temperature Fuel Cells, Solid Electrolytes, 1987 by Academic Press, Inc., pp. 431 ff.
- D.C. Fee et al., Monolithic Fuel Cell Development, Argonne National Laboratory, Paper presented at the 1986 Fuel Cell Seminar, Oct. 26 - 29, 1986 Tucson, AZ, U.S. Department of Energy, The University of Chicago.

PRESENTATION OF THE INVENTION

The object of the invention is to present a current collector for carrying current between flat, planar, stacked high-temperature fuel cells with a solid electrolyte that, arranged on both sides of the separating plate dividing the intermediate space between adjacent fuel cells into two spaces carrying the different gaseous media, fuel and oxygen carrier, will guarantee excellent current transfer with minimal losses both to the contact points and in the electrical conductor itself and that will assure unchanged, long-time stable operation without interruption. The current collector should be reproducible and cost-effective to produce and should be easily replaceable during intentional stoppages for control and inspection.

This object is achieved in that the current collector of the type mentioned at the outset is made of a plurality of elastic elements that have long-term stability, are fully elastic at an operating temperature of 800 to 1,000°C, provide in turn a plurality of electrical contact points, do not oxidize at least on the oxygen side or form a high-temperature protective oxide, made of a metallic and/or

ceramic material or of a composite material containing metallic and/or ceramic components and that is made in such a way that, under a load of 10^3 Pa applied perpendicular to the plane of the plate, it has a deflection of at least 0.1 mm.

METHOD OF IMPLEMENTING THE INVENTION

The invention will be explained in greater detail below with the help of the exemplary embodiments shown in the figures.

The figures show:

Figure 1: an elevation/longitudinal section of a separating plate having a contact finger as current collector,

Figure 2: an elevation/longitudinal section of a separating plate with current collectors on either side and adjacent, parallel, planar fuel cells,

Figure 3: a plan view of a separating plate with current collector, gas side,

Figure 4: a plan view of a separating plate with current collector in the form of a comb,

Figure 5: an elevation/longitudinal section of a separating plate with current collector in the form of a double comb,

Figure 6: a plan view of a separating plate with current collector in the form of a double comb,

Figure 7: an elevation/longitudinal section and a side elevation/cross section of a separating plate and an adjacent fuel cell with helical shaped current collector in between,

Figure 8: a schematic elevation/longitudinal section and a side elevation/cross section of a current collector,

Figure 9: a schematic perspective view of the production of a helical current collector of a ceramic fiber,

Figure 10: an elevation/longitudinal section of a separating plate and an adjacent fuel cell with corrugated current collector in between,

Figure 11: a schematic perspective view of a corrugated current collector,

Figure 12: a schematic longitudinal section of a profiled current collector of wire mesh,

Figure 13: a schematic section of a profiled current collector of metal fabric,

Figure 14: an elevation/longitudinal section of a separating plate and an adjacent fuel cell with acutely corrugated current collector in between,

Figure 15: a schematic perspective view and a cross section of a current collector that is corrugated in two planes, /4

Figure 16: a schematic elevation/cross section and a side elevation of a current collector corrugated in two planes, made of a plurality of wire elements,

Figure 17: a schematic plan view of a current collector acutely corrugated in two planes,

Figure 18: an elevation/longitudinal section of a separating plate and an adjacent fuel cell with current collector sintered on in between,

Figure 1 shows an elevation/longitudinal section of a separating plate with a contact finger as current collector. 1 is the gas-tight, planar separating plate made of a heat-resistant, oxidation-resistant alloy or of a dense electrically conductive ceramic material. Firmly connected to it in an electrically conductive manner is an individual element **2** of the current collector, in the form of a contact finger.

Figure 2 shows an elevation/longitudinal section of a separating plate with current collectors on either side and adjacent, parallel, planar fuel cells, Reference number 1 indicates the gas-tight, electrically conductive separating plate, on which current collector **3** consisting of numerous contact fingers, is attached on the fuel side. A corresponding, symmetrically arranged current collector **4** is located on the oxygen side. Each of the adjacent fuel cells in contact with current collectors **3** and **4** consists of the ceramic solid electrolyte (doped, stabilized ZrO_2) **5**, porous (positive) oxygen electrode **6** of La/Mn perovskite, and porous (negative) fuel electrode **7** of Ni/ZrO_2 cermet. Current collectors **3** and **4** are made of a plurality of crosswise arranged individual contact fingers in a plurality of parallel planes.

Figure 3 shows a plane view of a separating plate with current collector on the gas side. This embodiment essentially corresponds to the top part of Fig. 2. On the separating plate, which is rectangular of square in the plan view, are contact fingers **2**, arranged in a plurality of planes, which collectively form current collector **3**.

Figure 4 shows a plane view of a separating plate with a current collector in the form of a comb, Current collector **8** in the form of a comb is a contiguous body made of a plurality of individual contact fingers of metal sheet or band. The rib of this comb-like formation is firmly connected to separating plate 1 by connecting points **9** (welded or soldered joints).

Figure 5 shows an elevation/longitudinal section of a separating plate with current collector in the form of a double comb, Reference number 10 is such a current collector in a 1st row, 11 a current collector in a 2nd row, offset with respect to the 1st row. The current collectors, stamped out of metal sheet, are similarly attached to separating plate **1** in a manner similar to Fig. 4.

Figure 6 shows a plane view of a separating plate with a current collector in the form of a double comb. The arrangement essentially corresponds to that of Fig. 5. The various double combs are interlaced in one another so as to form a crosswise arrangement, covering as large a surface as possible.

Figure 7 shows an elevation/longitudinal section and a side elevation/cross section of a separating plate and an adjacent fuel

cell with a helical shaped current collector in between. Lodged between separating plate 1 and fuel cell (5; 6; 7) is a current collector 12, in the form of a slanted helix (coil spring). The windings of the helix lying on separating plate **1** are firmly attached to it at connecting points **13** (welded joint, soldered joint, sinter point). Due to the slant of the windings relative to the longitudinal axis of the helix, a relatively weak spring (low spring constant) is formed, which is desirable for accommodating unevenness.

Figure 8 shows a schematic elevation/longitudinal section and side elevation/cross section of a helical current collector. The representation corresponds to that of Fig. 7 and shows the deformation and displacement occurring under force, p, applied perpendicular to the plane of the plate. Reference number 12 shows the current collector under load, p, while 12* is the current collector in the state without load. The cross section of the helix, which is already elliptical due to the slant of the helix, is given added eccentricity by the load.

Figure 9 shows a schematic perspective view of the production of a helical current collector of a ceramic fiber, A vessel **14** is provided for ceramic melt **15**. Reference number 16 indicates a rotating, longitudinally displaceable mandrel, on which a thin cast jet (fiber 17) is applied from ceramic melt **15**. The rotary and longitudinal motion of mandrel **16** is indicated by the arrows.

Reference number 18 is the helix produced in this way from ceramic melt **15**.

Figure 10 shows an elevation/longitudinal section of a separating plate and an adjacent fuel cell with corrugated current collector in between. Corrugated current collector 19*, made of wire, band, mesh, net, or screen, is shown in the state that results under the influence of a load (pressure, p) perpendicular to the plane of the plate. Reference number 1 indicates the separating plate; fuel cell (5; 6; 7), which actually consists of 3 layers, corresponds to that of the previous figures. Reference number 19* indicates the original shape of the current collector not under load. /5

Figure 11 shows a schematic perspective of a corrugated current collector. Current collector **19**, which is made of individual corrugated wires, has on each of two opposite sides a reinforcing strip **20** as a transverse connector. The waves of individual wires **19** are offset, in order to provide as uniform a distribution as possible of the pressure acting on the contact points over the entire plane of the plate and to provide good current transfer.

Figure 12 shows a schematic longitudinal section of a profiled current collector of wire mesh. Current collector **21** is made in the form of a wire mesh that is corrugated or provided with nodules and recesses. The profiles (outward bends, inward bends) in one row are offset with respect to those of the next row by a half pitch, in order

to produce contact as uniform as possible over the entire cross section of the separating plate and of the fuel cell.

Figure 13 is a schematic section of a profiled current collector of metal fabric. In this case, it is a current collector **22** in the form of a pleated fabric. The deformation and displacement relationships in this arrangement are comparable to those of Fig. 10.

Figure 14 shows an elevation/longitudinal section of a separating plate and an adjacent fuel cell with acutely corrugated current collector in between. Reference numbers 1, 5, 6, and 7 correspond exactly to those of Fig. 10. Reference number 23 indicates a current collector in the form of an acutely corrugated wire. This reduces the contact surfaces, compared to those of the classic sinusoidal shape, thereby increasing the specific contact pressure accordingly.

Figure 15 shows a schematic perspective and cross section of a current collector that is corrugated in two planes. The wire, originally found as a sinusoidal line in one plane (indicated by a broken wavy line), is bent into two planes at a certain angle (e.g., 120°) about its center line. Reference number 24 shows this current collector in the form of a wire that is corrugated in two planes.

Figure 16 shows a schematic elevation/cross section and a side elevation of a current collector that is corrugated in two planes, comprising a plurality of wire elements. Current collectors **25**, with an upside-down V-shaped cross section in the form of wires corrugated in two planes, alternate with corresponding right-side-up current

collectors 26. Both groups (25 and 26) are held together on opposite sides by reinforcing strips **20** as transverse connectors.

Figure 17 shows a schematic plane view of a current collector that is acutely corrugated in two planes. The basic design corresponds to that of Fig. 16. Here, however, the corrugations are pointed, in order to keep the contact surface at the top of the sinusoidally curved part small. The reference numbers correspond to those in Fig. 16.

Figure 18 shows an elevation/longitudinal section of a separating plate and an adjacent fuel cell with a sintered-on current collector in between. The design is quite similar to that of Fig. 1. The reference number 1 indicates the separating plate, made of a heat-resistant alloy, and 2 an individual element of the current collector. Instead of a contact finger that is thickened at the end, in this case there is a sintered connection **27** with porous fuel electrode **7**, made of Ni/ZrO_2 cermet. Reference number 5 is the solid electrolyte of ZrO_2 and 6 the porous oxygen electrode. Heat expansion is absorbed by elastic deformation of the relatively long fin-like part of current collector **2**.

Exemplary embodiment 1:

(c.f. figures 1, 2, and 3)

A current collector of individual contact fingers **2** and a separating plate **1** was made of a heat-resistant, oxidation-resistant iron-based alloy, with the German DIN standard material number 1.4762, having the designation X10CrAl24. The material had the following composition:

Cr = 24 wt%

Al = 1.5 wt%

Si = 0.9 wt%

Mn = 0.8 wt%

C = 0.10 wt% /6

Fe = Remainder

The 0.8 mm thick separating plate 1 was rectangular and had a length of 70 mm and a width of 35 mm. Contact fingers **2**, made of the same material by rolling a wire, had the following dimensions:

Length:	ca. 21 mm
Height on the oxygen side:	ca. 6 mm
Height on the fuel side:	ca. 3 mm
Width:	ca. 2 mm
Thickness:	ca. 0.2 mm

The foot of the contact finger to be connected to separating plate **1** had a length (horizontal) of ca. 3 mm, while the head located at the other end had a height (vertical) of ca. 1 mm. The angle enclosed between contact finger **2** and separating plate **1** was ca. 12°

on the oxygen side (air) and ca. 5° on the fuel side (CH_4). In each case, a contact finger **2** on the oxygen side and on the fuel side was firmly joined to separating plate **1** in a spot-welding machine equipped with an appropriate fixture. In this way, more and more rows of contact fingers **2** were alternatingly mounted directed toward one side and the other to current collectors **3** (fuel side) and **4** (oxygen side). A total of 7 x 14 = 98 contact points were produced on a projected active surface of ca. 20 cm^2. Finally, the entire unit was adjusted by light pressing between plane-parallel steel jaws such that the height difference among the individual contact fingers **2** was less than 0.1 mm. With a specific load of ca. $1.5 \cdot 10^3$ Pa perpendicular to the plane of the plate, the central deflection of contact finger **2** was ca. 0.2 mm. In this way, all unevenness and coarseness as well as manufacturing tolerances of adjacent fuel cells, made of ceramic solid electrolyte **5**, oxygen electrode **6**, and fuel electrode **7**, could be compensated. The current transfer to the contact points was guaranteed by an additional precious-metal coating on the heads of contact fingers **2**.

<u>Exemplary embodiment 2:</u>

(c.f. Fig. 4)

A component comprising several rows of contact finger similar to 2 (see Fig. 1) and a separating plate 1 for carrying current was made of stamped metal-sheet parts. The material used was a Fe/Cr/Al-alloy

with the DIN number of 1.4767, with the designation CrAl 20 5. The material had the following composition:

Cr = 20 wt%
Al = 5 wt%
Si = 0.8 wt%
Mn = 0.7 wt%
C = 0.08 wt%
Fe = Remainder

Separating plate 1 had the same dimensions as in Example 1. A number of current collectors **8** were stamped from a 0.2 mm thick metal sheet in the form of a comb. The individual contact fingers had a width of 1.2 mm. The lateral intermediate space between two contact fingers was 2 mm. The back of the comb consisted of a strip ca. 3 mm wide. The combs were made by pressing into the shape of the individual contact finger in Fig. 1, whereby the geometry was largely that of Example 1. The combs were pushed into each other such that the remaining lateral intermediate space (play) between adjacent, crossing contact fingers was 0.4 mm. During assembly, the combs with their strips were attached by spot welds **9** to separating plate **1** and, in addition, firmly attached over the entire surface by a high-temperature solder. The soldering was carried out under a vacuum at a temperature of 1,200°C. The sharp edges produced on the heads of the contact fingers during stamping were etched and rounded off. The finished bodies were adjusted in the same manner as in example 1. /7

Exemplary embodiment 3:

(c.f. Figs. 5 and 6)

As in Example 2, current collectors **10** and **11** were stamped from metal sheets in the form of double combs, pressed into the angled shape, and joined to separating plate **1** by spot welding and hard soldering. For both double combs **10**, **11** and separating plate **1** a Ni/Cr alloy having the DIN material number 2.4869 with the designation NiCr 8020 with the following composition was used:

Cr = 20 wt%
Si = 1.2 wt%
Mn = 0.8 wt%
Cu = 0.4 wt%
Cn = 0.12 wt%
Ni = Remainder

The separating plate had a thickness of 0.6 mm, a length of 50 mm, and a width of 30 mm. The individual contact fingers of a double comb had the following dimensions:

Length:	ca. 7 mm
Height on the oxygen side:	ca. 3 mm
Height on the fuel side:	ca. 2 mm
Width:	ca. 0.8 mm
Thickness:	ca. 0.08 mm

The lateral intermediate space between two contact fingers was 1.4 mm. The remaining lateral play between adjacent, crossing contact fingers was therefore 0.3 mm. Otherwise, the process was exactly like that indicated under Example 2.

Exemplary embodiment 4:

(c.f. Figs. 7 and 8)

The current-carrying component consisted of a gas-tight electrically conductive separating plate **1** and a current collector **12**, in the form of slanted helices. The material NiCr80 20 mentioned in Example 3 was used for both.

The smoothly polished separating plate **1** had a thickness of 0.3 mm. A 0.15 mm wire was wound into a helix (coil spring) of ca. 7 mm winding diameter and divided into sections corresponding to the width of separating plate **1**. Then the ends of each helix were attached to separating plate **1** by spot welding. Then the helices were deformed by applying a load perpendicular to the plane of the plate with a horizontal thrust in their longitudinal axis so that the turns assumed an oval cross section and the windings stood at a slant to the plane of the plate (c.f, Figs. 7 and 8). The height of the helix perpendicular to the plane of the plate was ca. 3 mm on the fuel side and 4 mm on the oxygen side. The entire piece was kept in this position in a heat-resistant device under a vacuum for 5 h at a temperature of 980°C. In this way, the individual turns of current collector **12** were sintered to separating plate **1** at their points of contact (sinter points 13). In this way, moreover, an irreversible hot forming is achieved, so that after cooling and strain relief the windings of the helix do not return to their original cylindrical shape. The elastic properties were largely retained, however. Under a

load of 2 · 10^{-2} N per winding applied perpendicular to the plane of the plate the current collector 12* gave ca. 0,22 mm.

Exemplary embodiment 5: /8

(c.f., Fig. 9)

The current collector on the fuel side has approximately the geometric shape of a slanted helix (c.f., 12 in Fig. 7). It was produced from a ceramic melt **15** in the form of a cast jet **17** on a rotating, longitudinally displaceable mandrel **16**. Silicon carbide was used as the raw material, since it possesses a relatively good metallic electrical conductivity at the operating temperature. Helix **18**, of solidified ceramic melt, was produced directly in its final slanted form, in that mandrel **16** was programmed to move in the directions indicated by the arrows.

Separating plate 1 (c.f., Fig. 7) was made as a ceramic composite and on the fuel side consisted of a 1.5 mm thick plate of densely sintered silicon carbide and on the oxygen side of a 200 µm thick layer of strontium-doped La/Mn perovskite, applied by the plasma-spray method. In between there was a 60 µm thick nickel layer, previously electroplated onto the silicon carbide plate, as a diffusion barrier. Several helices **18** were turned into one another in a screw-like manner, producing a kind of "carpet" with numerous contact points.

Their ends were affixed to separating plate **1** with a ceramic adhesive. The entire piece was then sintered for 20 h at a temperature

of 1,400°C under an argon atmosphere. This produces firm points of connection at the contact points of the windings (c.f., 13 in Figs. 7 and 8). The deflection was ca. 50 μm under a load of $5 \cdot 10^{-2}$ N per winding.

Exemplary embodiment 6:

(c.f., Fig. 10)

Using a 0.15 mm thick, 1.2 mm wide band, corrugated current collectors **19** were produced from the iron-based alloy X10CrAl24 (c.f., Example 1). A plurality of such bands were spot welded at one end via a planar band-shaped strip (c.f., Fig. 11). In the unloaded state, the current collectors had the shape indicated by the reference number 19*. Under the influence of the load (pressure p), they were able to be freely deformed and move laterally, as indicated by the reference number 19 (operating state).

The corrugated shape need not necessarily be sinusoidal. Any wavy forms, such as triangles, rectangles, trapezoids, asymmetric, slanted waves, etc. can be used. The shapes depend, among other things, on the spring constant (rigidity, deflection) of the current collectors that is to be achieved.

Exemplary embodiment 7:

(c.f., Fig. 10)

As in Example 6, corrugated current collector **19** comprised a comb-like body of a 0.1 mm thick stamped metal sheet (c.f., Fig. 4), whose 1 mm wide strips were then corrugated in a rolling device. The wavelength was ca. 6 mm. The deflection in the installed state under a load of ca. $5 \cdot 10^{-2}$ N per wave perpendicular to the plane of the plate was ca. 0.10 mm.

Exemplary embodiment 8:

(c.f., Fig. 11)

Corrugated current collectors **19** were made of the Fe/Cr/Al /9 alloy CrAl20 5 from a 0.25 mm thick wire (c.f., Example 2). A plurality of such wires were spot welded at both ends via a flat band-shaped reinforcing strip **20** (transverse connection) to form a lattice-like body. This current collector was then placed on a polished separating plate **1** of the same material, placed under a load perpendicular to the plane of the plate, and sintered on at the points of contact under a vacuum at 1,200°C for 3 h (locally welded). Unlike in Example 6 (Fig. 10), lateral is not allowed in this case. Due to the low moment of resistance of the relatively thin wire, the required compliance is provided in the vertical direction.

Exemplary embodiment 9:

(c.f., Fig. 12)

A current collector **21** in the form of a wire mesh provided with nodules and recesses is produced of pure nickel for the fuel side. For the oxygen side, the alloy NiCr80 20 (c.f., Example 3) was used. The mesh width of the wire mesh was ca. 0.3 mm, the wire thickness 0.1 mm. The wire meshes were shaped in a press device to a 2 or 3 mm high profiled body with waves and nodes. The contact distances obtained in this way were 2.5 to 6 mm, so that a contact density of ca. 13 to 15 contact points per cm^2 could be achieved. The deflection under a load of $8 \cdot 10^{-2}$ N per elevation was ca. 0.08 mm.

Exemplary embodiment 10:

(c.f., Fig. 13)

A current collector **22** was produced in the form of a pleated fabric. The material used for the metal fabric, X10CrA124, was the same as in Example 1. The wire in the metal fabric had a diameter of 0.1 mm. The mesh width was 0.6 mm. The fabric was pleated in folds with a pitch of ca. 3 mm and a total height (double the amplitude) of ca. 1.6 mm. The mean distance between point-like contacts was ca. 3 mm. Under a vertical load (perpendicular to the plane of the plate) of ca. $80 \cdot 10^{-3}$ N per contact point, the deflection of the current collector was ca. 0.05 mm.

Exemplary embodiment 11:

(c.f., Fig. 14)

In this example, the idea was to reduce the effective active surface of the electrical contact points, in order to increase the specific contact pressure and to achieve as low a contact resistance as possible. This was achieved by making a current collector **23** in the form of an acutely corrugated wire. For this purpose, a wire originally in relatively flat sinusoidal or trapezoidal waves was pressed into a shape that pressed the crest of the waves outward in such a way as to increase the amplitude. This produced a relatively sharply tapered crest part with a small radius of curvature and a relatively high rigidity. The starting material was a wire 0.25 mm in diameter made of the material $CrAl_2O_5$. The wavelength was 12 mm and the total height (twice the amplitude) ca. 3.5 mm. Under a force of 35 $\cdot 10^{-3}$ N per contact point, the deflection perpendicular to the plane of the plate was 0.15 mm.

Exemplary embodiment 12:

(c.f., Fig. 15) /10

A current collector **24** was produced in the form of a wire, corrugated in two planes. A 0.25 mm thick wire of X10CrAl24 material was first made into approximately sinusoidal waves of 12 mm wavelength and 5 mm amplitude in one plane. This corrugated shape was then folded along the longitudinal axis (node line, zero crossing of the

sinusoidal curve) in such a way that, as seen in cross section, a V-shaped body with an opening angle of approximately 107° was formed. Thus, the spacing in the crest line of the sinusoidal curve (V-opening width) was ca. 8 mm and the height of the V-shaped body ca. 3 mm. Under a force of $40 \cdot 10^{-3}$ N per contact point, the deflection perpendicular to the plane of the plate was 0.12 mm. A plurality of such folded, corrugated current collectors **24**, in each case offset by a half pitch, were nested in one another to form a unit, joined to a separating plate of the same material, by affixing the waves at both ends with a spot weld at the node points. This fully elastic design, with long-term positional stability, achieved excellent adaptation to the unevenness and manufacturing tolerances of the adjacent components.

Exemplary embodiment 13:

(c.f., Fig. 16)

A body serving as overall current collector was produced from individual wires of the material CrAl205 as follows. A wire 0.12 mm in diameter was first shaped into a sinusoidal wave of ca. 10 mm wavelength and 1.5 mm amplitude and, as in example 11 (c.f., Fig. 14) made into an acutely corrugated form by stretching at the zero crossings and bending out at the crests. Then every second wave, measured from a crest point to the next but one, was displaced by an angle of 60° (like the teeth of a saw blade), in such a way that, as viewed in cross section, a V-shaped body was formed. Then,

alternatingly, an upside-down current collector **25** was arranged beside a right-side-up current collector **26**, offset by a half wavelength, and the entire piece was affixed with reinforced end strips **20** (transverse connections) by spot welding. The height of the complete current collector was ca. 2.7 mm. The deflection was ca. 0.15 mm under a contact force of $60 \cdot 10^{-3}$ N per contact point.

<u>Exemplary embodiment 14:</u>

(c.f., Figs. 14, 16, and 17)

Using the same X10CrAl24 material as in Example 12, current collectors **25** and **26**, pointed and corrugated in two planes, were produced by folding with an opening angle of 60°. The wavelength was 12 mm, the amplitude 3.5 mm, and the wire thickness 0.15 mm. Upside-down current collectors **25** were alternatingly arranged without offset beside right-side-up current collectors **26** and connected to one another with strips **20**. The entire piece produced a body ca. 3 mm high. The deflection under a point-load of $80 \cdot 10^{-3}$ N per contact point was ca. 0.13 mm.

<u>Exemplary embodiment 15:</u>

(c.f., Fig. 18)

An individual element of a current collector **2** was welded onto a gas-tight, electrically conductive separating plate **1** of NiCr8020 material in the form of a contact finger of pure nickel. Separating plate **1** was 0.6 mm thick and the current collector was 0.15 mm thick.

The fuel cell consisted of solid electrolyte **5** and electrodes **6** and **7**. A sintered connection **27** was made with current collector **2** on the side of fuel electrode **7**, made of Ni/ZrO_2 cermet. For this /11 purpose, the point of contact was strewn with nickel powder with a maximum particle diameter of 5 µm and a point-load of $50 \cdot 10^{-3}$ N was applied. The entire piece was then sintered for 1/2 h at a temperature of 1,100°C under a vacuum. After strain relief no discernible contact resistance could be measured, neither at room temperature nor at the proposed operating temperature of 900°C.

The invention is not limited to the exemplary embodiments.

The current collector for carrying current between adjacent flat, planar, stacked high-temperature fuel cells (5; 6; 7) with a solid electrolyte (5) based on doped, stabilized zirconium oxide, whereby in each case oxygen electrode (6) of one fuel cell is electrically connected to fuel electrode (7) of the subsequent fuel cell and the intermediate space between electrodes (6; 7) is divided by a gas-tight, electrically conductive separating plate (1) in two spaces, which carry the different gaseous media, fuel and oxygen carrier, comprises a plurality of elastic elements that have long-term stability, are fully elastic at an operating temperature of 800 to 1,000°C, provide in turn a plurality of electrical contact points, do not oxidize at least on the oxygen side or form a high-temperature protective oxide, made of a metallic and/or ceramic material or of a

composite material containing metallic and/or ceramic components and that is made in such a way that, under a load of 103 Pa applied perpendicular to the plane of the plate, it has a deflection of at least 0.1 mm. In one embodiment, the current collector comprises a plurality of individual elements (2) in the form of a contact finger, whereby each individual element (2) is firmly connected to gas-tight, electrically conductive separating plate (1) in a force-locking and electrically conductive manner.

Preferably, the current collector comprises numerous, mutually crossing rows (3; 4) of contact fingers on both the fuel side and the oxygen side, firmly connected on both sides to separating plate (1), whereby the thickened ends of the contact finger are in contact on one side with porous oxygen electrode (6) of La/Mn perovskite and on the other side with porous fuel electrode (7) of Ni/ZrO_2 cermet, under a compression force of at least 10^2 Pa. It is advantageously made of a plurality of contact fingers in the form of a comb (8), whereby several such combs (8) are arranged nested crosswise and are attached with connecting points 9 to separating plate 1 or are made in the form of double combs (10; 11) which, in turn, comprise contact fingers connected to one another by a middle part, whereby the middle part is firmly connected to separating plate 1.

In another embodiment, the current collector comprises a plurality of slanted helices (12), under a pressure p acting

perpendicular to the plane of the plate, which can move freely along their longitudinal axis or are firmly connected at their connecting points (13) to separating plate (1) by welding, soldering, or sintering. In one variation, the current collector comprises at least one helix (18) of solidified ceramic melt.

In an additional embodiment, the current collector comprises a plurality of corrugated individual elements (19) of wire, band, mesh, fabric, or screen, whereby the ends of individual elements (19) are held together by a reinforcing strip (20) as a transverse connection. In this case, the variations are:

current collector comprising a wire mesh with nodes and recesses or of a corrugated wire mesh or pleated fabric; current collector comprising a plurality of acutely corrugated wires (23) that touch separating plate (1) and the opposite electrode (7) in a point-like manner; current collector a plurality of wires (24) kinked in two planes that, when viewed in profile, form a V-shape, forming contacts on one side by the kink, on the other side by the crest of the wave; current collector comprising a plurality of wires (25, 26) that are pointed and corrugated in two planes, whereby parallel arranged individual elements are arranged alternatingly upside down (25) and right-side-up with respect to the planes of the plates that are to be connected electrically and the ends are held together by a reinforcing strip (20), as a transverse connector.

Finally, the current collector preferably comprises a plurality of individual elements (2) in the form of a contact finger, whereby between individual element (2) and electrode (7) there is a firm, force-locking and electrically conductive sintered connection (27).

Claims /12

1. A current collector for carrying current between adjacent flat, planar, stacked high-temperature fuel cells (5; 6; 7) with a solid electrolyte (5) based on doped, stabilized zirconium oxide, whereby in each case oxygen electrode (6) of one fuel cell is electrically connected to fuel electrode (7) of the subsequent fuel cell and the intermediate space between electrodes (6; 7) is divided by a gas-tight, electrically conductive separating plate (1) into two spaces, which carry the different gaseous media, fuel and oxygen carrier, characterized in that it comprises a plurality of elastic elements that have long-term stability, are fully elastic at an operating temperature of 800 to 1,000°C, provide in turn a plurality of electrical contact points, do not oxidize at least on the oxygen side or form a high-temperature protective oxide, made of a metallic and/or ceramic material or of a composite material containing metallic and/or ceramic components and that is made in such a way that, under a load of 10^3 Pa applied perpendicular to the plane of the plate, it has a deflection of at least 0.1 mm.

2. A current collector as recited in Claim 1, characterized in that it comprises a plurality of individual elements (2) in the form

of a contact finger, whereby each individual element (2) is firmly connected to gas-tight, electrically conductive separating plate (1) in a force-locking and electrically conductive manner.

3. A current collector as recited in Claims 1 and 2, characterized in that it comprises numerous, mutually crossing rows (3; 4) of contact fingers on both the fuel side and the oxygen side, firmly connected on both sides to separating plate (1), whereby the thickened ends of the contact finger are in contact on one side with porous oxygen electrode (6) of La/Mn perovskite and on the other side with porous fuel electrode (7) of Ni/ZrO_2 cermet, under a compression force of at least 10^2 Pa.

4. A current collector as recited in Claims 1 and 2, characterized in that it comprises a plurality of contact fingers in the form of a comb (8) and that a plurality of such combs (8) are nested crosswise and attached to separating plate 1 by connecting points 9.

5. A current collector as recited in Claims 1 and 2, characterized in that it comprises a plurality of double combs (10; 11) nested crosswise in one another, the double combs, in turn, comprising contact fingers connected to one another by a middle part, said middle part being firmly connected to separating plate 1.

6. A current collector as recited in Claim 1, characterized in that it comprises a plurality of slanted helices (12), acted on by a pressure, p, perpendicular to the plane of the plate, the helices being freely movable along their longitudinal axis.

7. A current collector as recited in Claim 1, characterized in that it comprises a plurality of slanted helices (12), acted on by a pressure, p, perpendicular to the plane of the plate, said helices being firmly connected at their connecting points (13) to separating plate (1) by welding, soldering, or sintering.

8. A current collector as recited in Claim 6 or 7, characterized in that it comprises at least one helix (18) of solidified ceramic melt.

9. A current collector as recited in Claim 1, characterized in that it comprises a plurality of corrugated individual elements (19) of wire, band, mesh, fabric, or screen, whereby the ends of individual elements (19) are held together by reinforcing strip (20) as a transverse connection.

10. A current collector as recited in Claim 1, characterized in that it comprises a wire mesh with nodes and recesses or of a corrugated wire mesh or pleated fabric.

11. A current collector as recited in Claim 1, characterized in that it comprises a plurality of acutely corrugated wires (23) that are in point-wise contact with separating plate (1) and opposite electrode (7).

12. A current collector as recited in Claim 1, characterized in that it comprises a plurality of wires (24) that are kinked in two planes and, when viewed in profile, form a V-shape and forming contacts on one side by the kink and on the other side by the crest of the wave.

13. A current collector as recited in Claim 1, characterized in that it comprises a plurality of wires (25, 26) that are pointed and corrugated in two planes, whereby parallel arranged individual elements are arranged alternatingly upside down (25) and right-side-up with respect to the planes of the plates that are to be connected electrically and that the ends are held together by a reinforcing strip (20), which serves as a transverse connection.

14. A current collector as recited in Claim 1, characterized in that it comprises a plurality of individual elements (2) in the form of a contact finger, whereby between individual element (2) and electrode (7) there is a firm, force-locking and electrically conductive sintered connection (27).

Fig.1

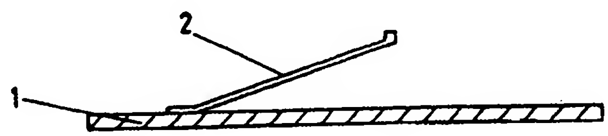

Fig.2

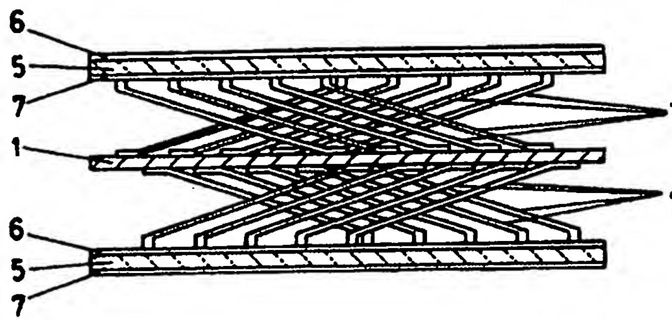

Fig.3

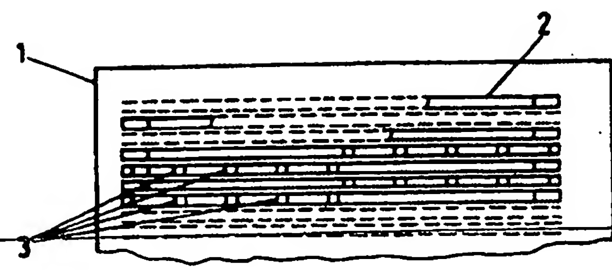

Fig.4

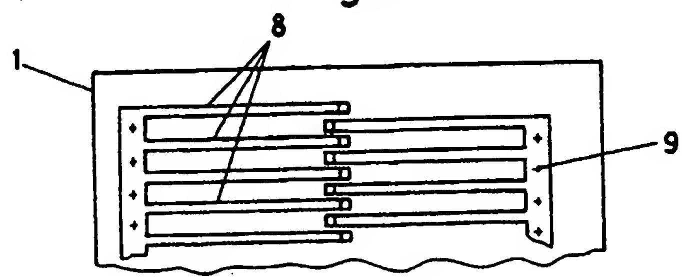

Fig.5

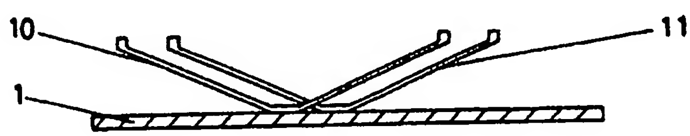

Fig.6

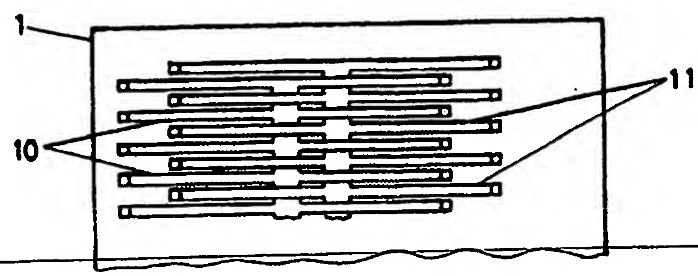

Fig.7

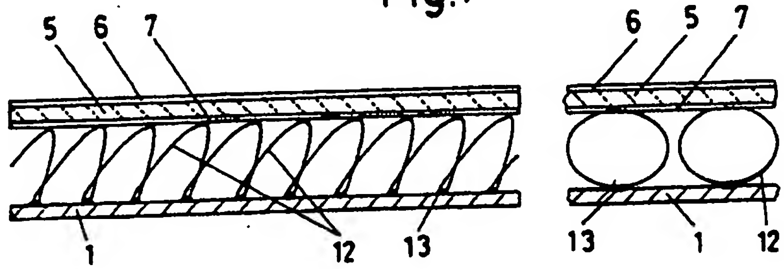

Fig.8

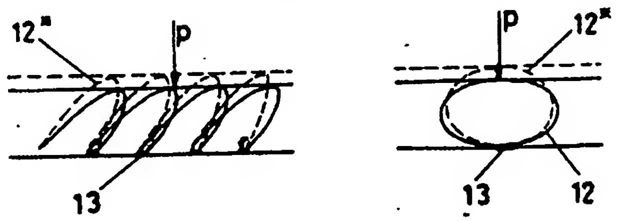

Fig.9

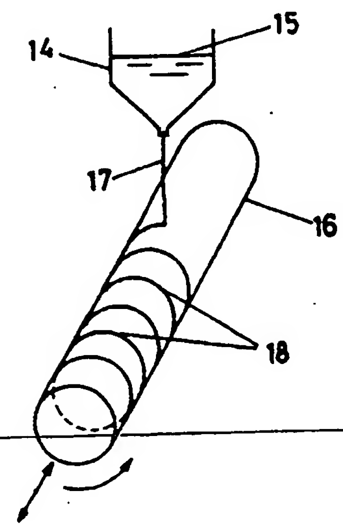

Fig.10

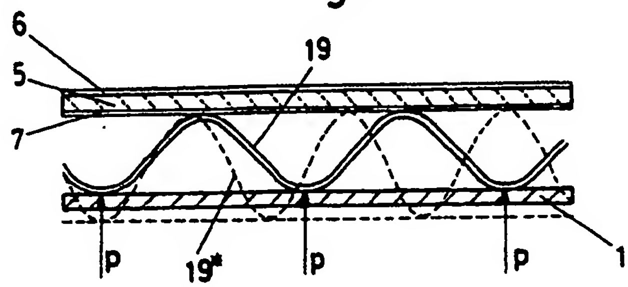

Fig.11

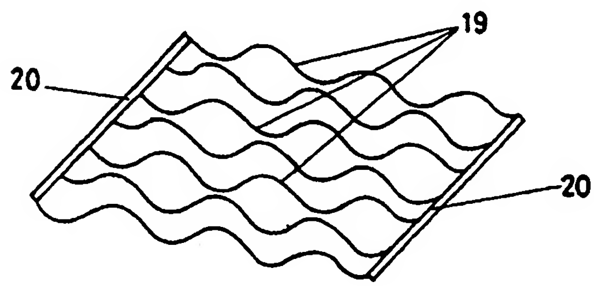

Fig.12

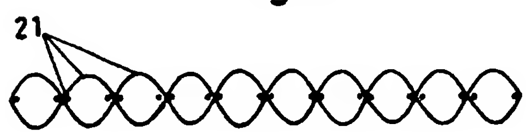

Fig.13

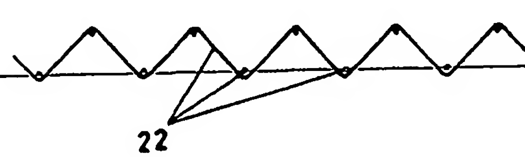

Fig.14

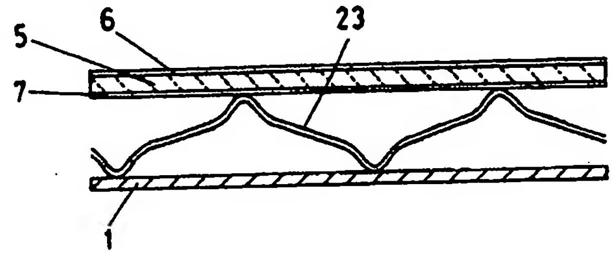

Fig.15

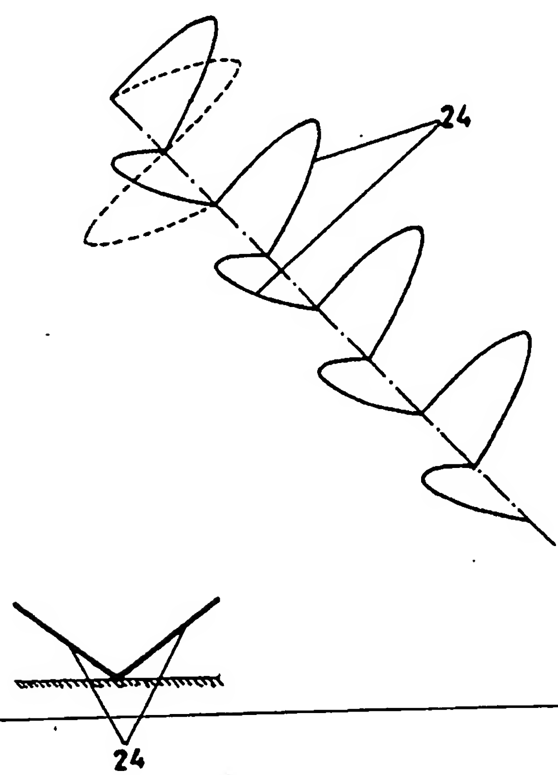

Fig.16

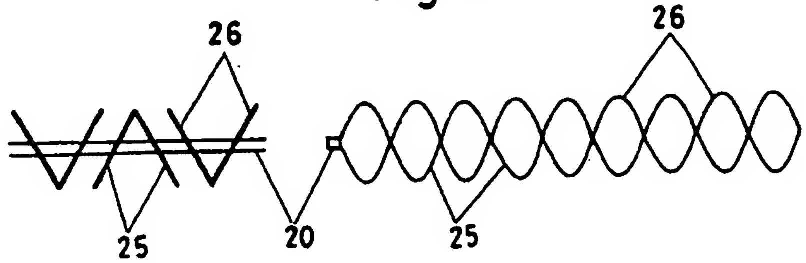

Fig.17

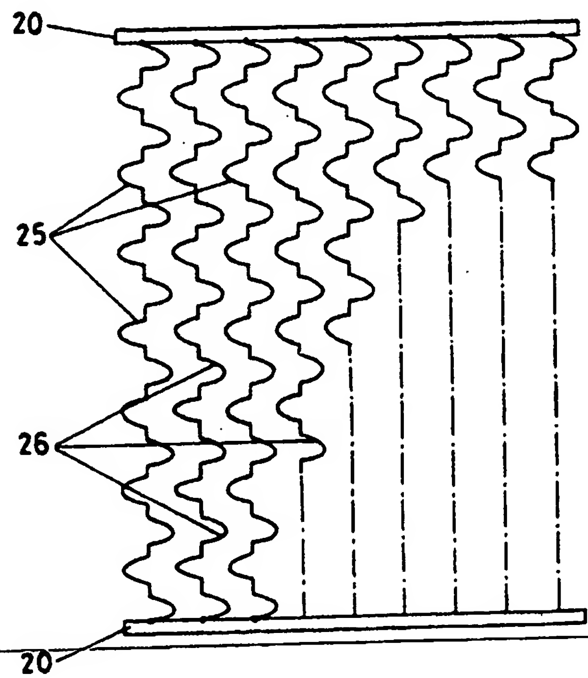

Fig.18